(12) UK Patent Application (19) GB (11) 2 264 601 (13) A

(43) Date of A publication 01.09.1993

(21) Application No 9226426.6

(22) Date of filing 18.12.1992

(30) Priority data
(31) 9127548 (32) 31.12.1991 (33) GB

(71) Applicant
3D Scanners Limited

(Incorporated in the United Kingdom)

Southbank Technopark, 90 London Road, London, SE1 6LN, United Kingdom

(72) Inventor
Stephen James Crampton

(74) Agent and/or Address for Service
Stephen Crampton
3D Scanners Limited, Southbank Technopark,
90 London Road, London, SE1 6LN, United Kingdom

(51) INT CL[5]
G01S 17/46, G01B 11/24

(52) UK CL (Edition L)
H4D DLRA D72X D730 D733 D745 D747 D748 D752 D757 D773 D775 D782 D783

(56) Documents cited
WO 92/08103 A1 WO 91/15732 A1 WO 89/09378 A1
US 5067013 A US 4541722 A US 4529305 A

(58) Field of search
UK CL (Edition L) H4D DLAT DLAX DLPC DLRA
INT CL[5] G01B
Online database: WPI

(54) Object inspection

(57) The invention relates to a scanning device 2 comprising at least a camera 4, a laser stripe generating means 3 comprising laser optics 7 and which produces two stripes of laser light, and a data processor 5 are enclosed. The scanning device 2 comprises at least two viewing means provided either by at least two cameras 4 or a single camera in combination with mirrors or lenses. The laser stripe generating means 3 and the viewing means are arranged with respect to each other such that regions on the surface of objects, which would be in shadow if a single incidence of laser light is used, can be seen directly by the laser stripe generating means 3 and viewed by the viewing means.

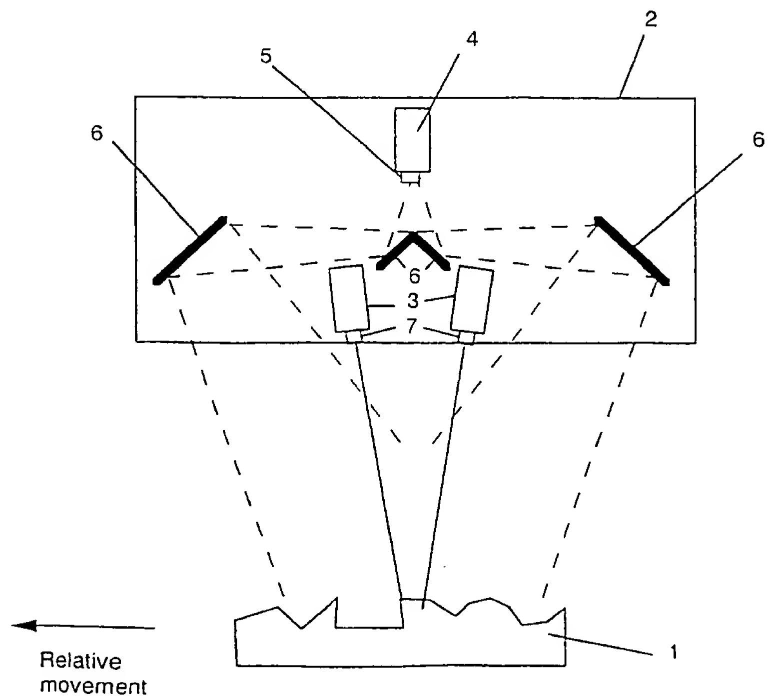

Figure 1.

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... originally filed was informal and the print reproduced here is taken from a later filed formal copy.

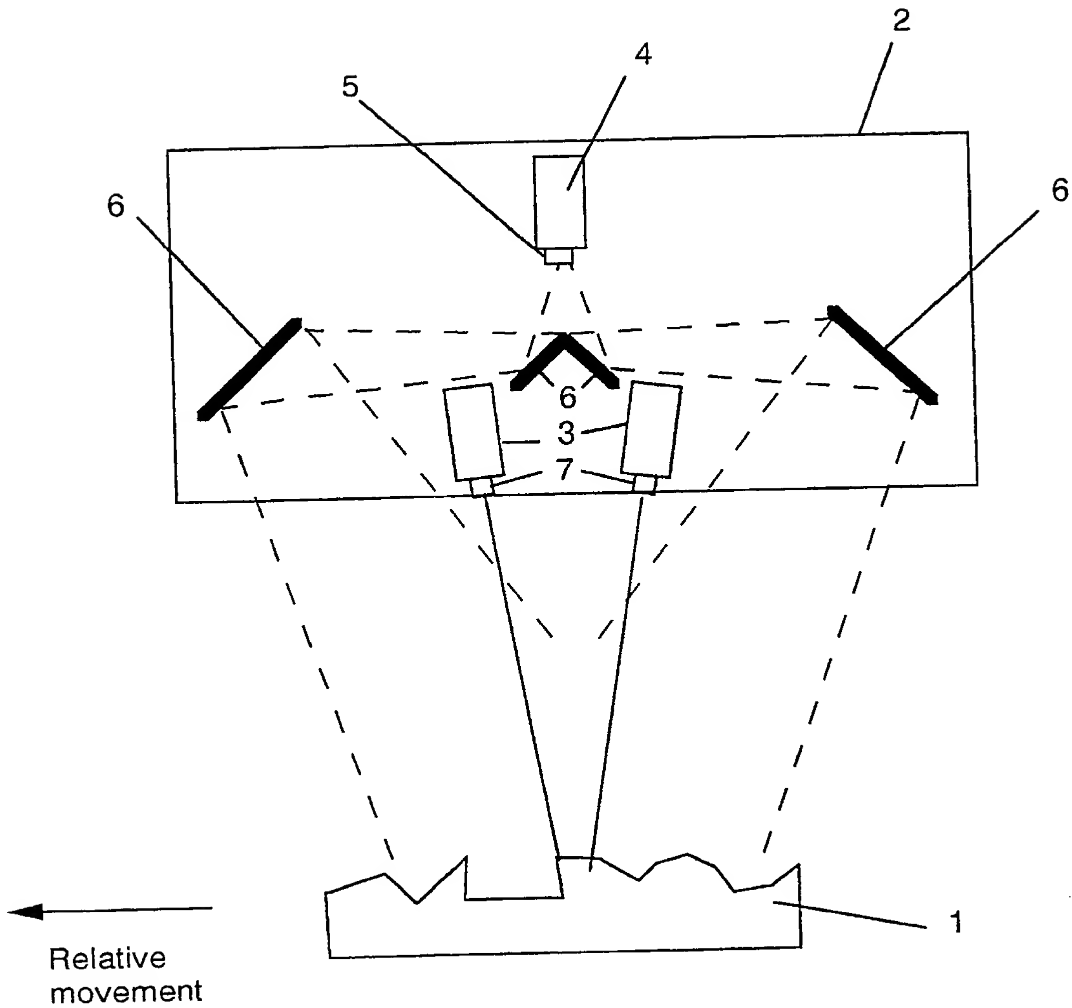

Figure 1.

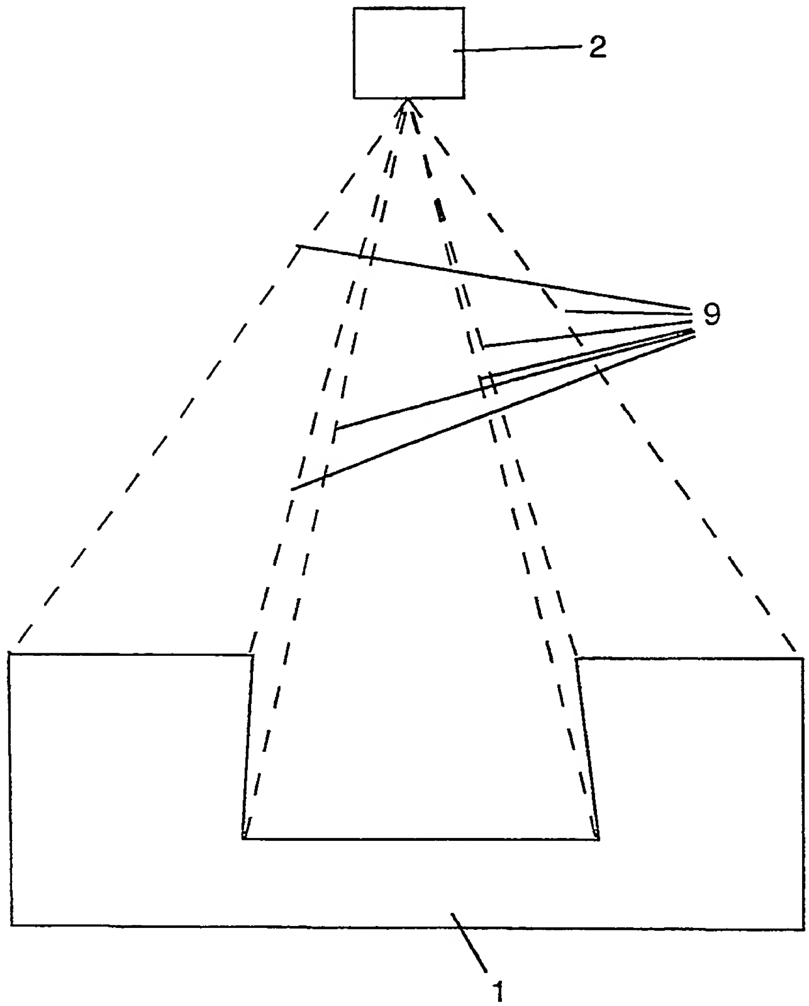

Figure 2.

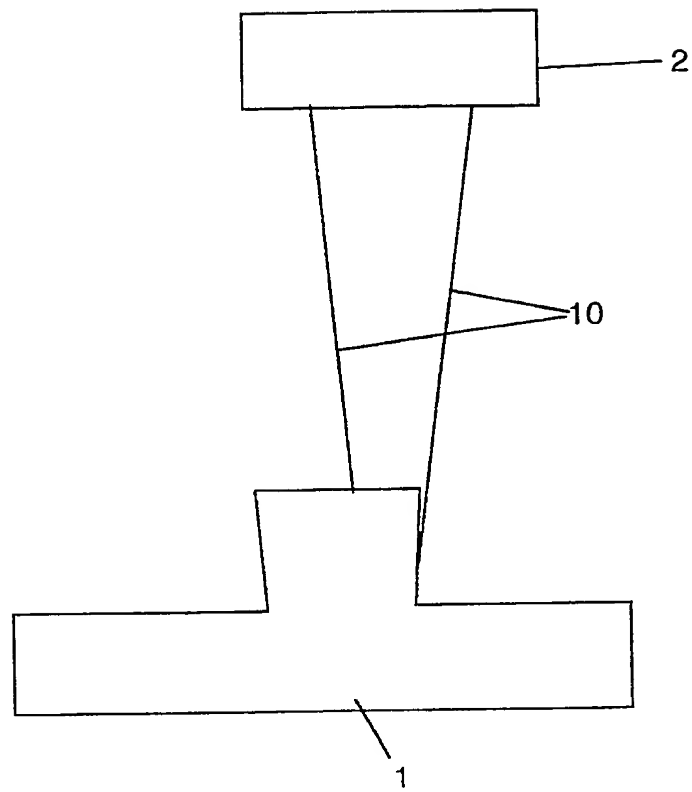

Figure 3.

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SCANNING SENSOR

This invention relates to a sensing device for the accurate, three dimensional surface scanning of an object.

There are numerous applications which require the accurate scanning (also known as digitising) of the surface of an object. The main uses are in reverse engineering and inspection. Examples of the main uses are: the reverse engineering of a model with free-form surface shapes for the production of tooling at a different scale to the original and the inspection of discrete products for the provision of pass/fail and trend information.

There are numerous methods of capturing the surface shape of an object, including a mechanical or optical or electromagnetic single point probe, holographic sensors, Moiré fringe systems, ultrasound sensors, fast Fourier transform systems, photogrammetric systems, time of flight sensors and triangulation techniques using structured light. Each method has different advantages and disadvantages in different classes of application.

The most common method of accurately scanning the surface of an object is with a mechanical sensor such as a touch-trigger probe mounted on a Coordinate Measuring Machine (CMM). A typical scan rate is 2 to 10 points per second. Since the touch-trigger probe is at a fixed vertical orientation, areas of the surface that are steeper than 3 degrees from the vertical usually cannot be scanned. Soft objects cannot be scanned accurately since the mechanical probe deforms the surface of the object on touching it.

More recently, optical single point probes based on laser triangulation have been used. These probes triangulate with one viewpoint which is normally a position sensing diode or a linear CCD sensor. They have higher scan rates than mechanical sensors since they are non-contacting and have no problem in scanning soft objects. However, optical single point probes cannot scan all surface textures and colours. There are also problems in scanning discontinuities such as edges. In addition, the path between the spot of laser light on the surface and the sensing device is sometimes obscured by the geometry of the object, causing an effect called shadowing (or eclipsing) in which measurements are lost.

It is an object of this invention to provide a new, three dimensional surface scanning sensor that may be mounted on a scanning machine such as a Coordinate Measuring Machine (CMM). The scanning sensor is connected by a cable to a special control and processing unit.

According to the invention, there is provided a scanning sensor which projects two stripes of laser light and views these two stripes from two viewpoints using the viewing means. There is relative movement between the scanning sensor and the object being scanned. The scanning sensor typically weighs around one kilogramme and would normally measure less than 300mm in size in any dimension.

The use of laser stripes and matrix CCD arrays rather than a single point with a linear CCD array or position sensing diode means that several hundred measurements may be made along the stripe simultaneously. The largest delay in scanning is the physical movement of the object relative to the scanner between each measuring position. The making of several hundred measurements at each position instead of one measurement at each position has several benefits.

Firstly, the scanning sensor has a faster data collection rate. Secondly, the scanning machine with a laser stripe need make only a few traverses to scan the whole object to a uniform density, rather than several hundred or thousand traverses as required by a single point sensor. Finally, the use of a laser stripe enables measurements to be made on vertical and slightly overhanging surfaces in the direction along the laser stripe.

The use of a CCD matrix rather than an area position sensing device or a linear position sensing device with a scanned spot/viewing point enables the processing unit to apply algorithms based on the knowledge of the light levels at each point in the matrix. These algorithms can determine not only the position but can identify well-known situations when errors in position are likely and to either output error signals or to compute accurate positions taking into account the full data. Position sensing devices do this process in hardware with the disadvantage that false positions may be generated due to optical effects such as those found at the edge of an object when part of the projected light is lost or from flare and reflections at a shoulder. The position sensing device cannot output error signals or provide the raw data that a CCD matrix can for calculating a more accurate position.

The two laser stripe generators are oriented towards each other. This enables surfaces that are vertical or slightly overhanging in the direction of scanning to be scanned. The laser stripe generators may be individually controlled such that each matrix CCD array exposure may contain light from either one or both stripes. In some complex surfaces the ability to have light from just one stripe at a time can avoid confusion in the processing if the two stripes meet in the CCD array image.

Laser projection optics are used to provide a laser stripe that is typically less than 100μm in width. The laser projection optics typically include focusing and defocusing elements, together with a stripe generating element.

It is also an object of this invention, to have the facility to control the power of the lasers, the exposure time of the CCD matrix array and the gain of the CCD for each measurement. With this method, if some parts of the laser stripe are not visible with a standard exposure at low laser power, then a second exposure (at the same physical position relative to the object) which is either longer or with more laser power can be made to render these points visible.

The laser sources may be broadband or narrowband. The use of a broadband laser source can overcome some optical characteristics generated by the surface texture. An example is the generation of speckle patterns by the interaction of a narrowband source with a machined surface. The speckles thus produced distort the stripe such that any measurements made are significantly less accurate than without the speckle effect.

The provision of two view points may be achieved by means of two CCD matrix arrays or by one CCD matrix array and four mirrors. The two view points overcome most shadowing problems in that if a part of the laser stripe is obscured from one viewpoint, then it is often visible from the other viewpoint. The scanning sensor may be traversed in either direction perpendicular to the stripe and due to its symmetry will achieve the same results. This is not true for one viewpoint due to shadowing and the scanning sensor is thus more flexible in use with two viewpoints than with one viewpoint.

External to the scanning sensor, a processing unit would typically calculate the centre of the stripe at each point to sub-pixel accuracy by using algorithms such as centre of gravity interpolation. It would also control laser powers and CCD matrix array exposures by real-time processing of the previous exposure.

The processing unit may be used to generate move commands to a machine that will change the relative distance between the object and the scanning sensor, allowing for the adaptive scanning of objects in which the variation in height of the object's surface is greater than the depth range of the scanning sensor. The lead stripe can provide advance information before the trailing stripe passes, allowing for the trailing stripe to be moved into range to scan what the lead stripe may have missed. This information can be used to generate the increment to the next scanning traverse. On a steep sided object, the scan increments between the traverses may be much less than on an object that is realtively flat; the generation of scan increments may be carried out adaptively and the increment can be changed so as to vary along a traverse.

The scanning sensor is fast and for an ideal object, data capture speeds of more than 12,000 measurements per second are obtainable.

The scanning sensor which is the subject of this invention is novel in that the unique combination and orientation of the CCD matrix array, laser and optical components into one scanning sensor provide a sensing device that is highly effective in accurately scanning an object more completely and more rapidly than other sensors available on the market.

A specific embodiment of the invention will now be described with reference to Figure 1 which is an outline of the scanning sensor layout.

A scanning device [2] comprising a camera [4], a laser stripe generating means [3], comprising laser optics [7], and at least one mirror [6], characterised in that the scanning device [2] projects at least two stripes of laser light [10] and has at least two viewing means.

The object being scanned [1], moves relative to the scanning sensor [2]. The scanning sensor is a rigid enclosure to which the components [3,4,5,6,7] are firmly attached such that there is no scope for movement of the components [3,4,5,6,7] relative to each other in normal operation. The scanning sensor operates on the principal of structured light triangulation. The sources of structured light are usually two lasers [3] at an angle towards each other, but may be one laser and an optical arrangement of mirrors and beam splitters. The source could be a slit of light or any other source that projects a relatively thin stripe of light onto the object [1]. The light stripe(s) are viewed at an angle by at least one CCD matrix array camera [4]. Camera optics [5] may be used to change the field of view. The preferred method is a lens of fixed focal length. Anamorphic optics in which the focal length in orthogonal directions is variable may also be used. The CCD matrix array camera(s) may not view the object directly and instead their optical paths may include reflection by means of a system of mirrors [6].

Laser optics [7] may be used in conjunction with the laser to produce stripes of different thicknesses. One method is to use a rod lens, which spreads a beam of light into a stripe of light. The rod lens may be used in conjunction with focusing optics to focus the thickness of the stripe at a certain distance from the optics. A second method is the use of a scanning element such as a polygon mirror or galvanometer mirror to scan a spot to produce a stripe.

In Figure 2 it is shown that the scanning sensor [2] has the capability of measuring points on the undercut surface of slight overhangs on the object [1] in the direction of the stripe. The lines of sight [9] are shown. For a complex surface, the scans can be overlapped so that no information is lost by shadowing along the stripe. Overlapping of the traverses by up to two thirds is enough to capture the vertical surfaces and slight

overhangs along the stripe. In practice, the overlap could be much less than this. An alternative scanning strategy is to scan the entire object with a very small overlap between traverses and from this information, the processing unit can identify the areas where data is missing and generate commands to the machine to go back and scan these areas until the complete surface is captured.

Similarly, in Figure 3 it is shown that the scanning sensor [2] has the capability of measuring points on the undercut surface of slight overhangs on the object [1] in the direction of scanning. The lines of laser light [10] are shown.

CLAIMS

1. A scanning device [2] comprising a camera [4], a laser stripe generating means [3], comprising laser optics [7], and at least one mirror [6], characterised in that the scanning device [2] projects at least two stripes of laser light [10] and has at least two viewing means.

2. A scanning device according to claim 1, characterised in that the viewing means are provided by at least two cameras [4].

3. A scanning device according to claim 2, characterised in that the viewing means are provided by a combination of at least one camera [4] and at least one mirror [6].

4. A scanning device according to claims 1 to 3, characterised in that the laser stripe generating means [3] comprises at least two lasers.

5. A scanning device according to claims 1 to 4, characterised in that the laser stripe generating means [3] and the viewing means are arranged with respect to each other such that regions on the surface of objects, which would be in shadow if a single incidence of laser light is used, can be seen directly by the laser stripe generating means [3] and viewed by the viewing means.

6. A scanning device according to claims 1 to 5 characterised in that the laser stripes are in parallel planes.

7. A scanning device according to claims 1 to 5, characterised in that the laser stripes are co-planar.

8. A scanning device according to claims 1 to 5, characterised in that the laser stripes are in coincident planes.

9. A scanning device according to claims 1 to 5, characterised in that the laser stripes are divergent.

10. A scanning device according to claims 1 to 9, characterised in that the two or more lasers may be switched on and off such that only one laser is switched on at any one time.

11. A scanning device according to claims 1 to 10, characterised in that the laser optics [7] can be adjusted to focus the stripes at different distances from the scanning device.

12. A scanning device according to claims 1 to 11, characterised in that the laser optics [7] include a rotating element for scanning a spot to achieve a stripe.

13. A scanning device according to claims 1 to 11,

characterised in that the laser optics [7] use fixed optical elements.

14. A scanning device according to claims 1 to 13, characterised in that the laser optics [7] include a device for optically generating at least two stripes [10] from a single laser [3].

15. A scanning device according to claims 1 to 14, characterised in that the camera [4] comprises camera optics [8] which can be adjusted to scan objects at different distances from the scanning device.

16. A scanning device according to claims 1 to 15, characterised in that the camera optics comprise anamorphic optics.

17. A scanning device according to claims 1 to 16, characterised in that the camera [4], laser [3] and mirror [6] are fixed in position with respect to each other in the rigid enclosure of the scanning device [2].

18. A scanning device according to claims 1 to 17, characterised in that algorithms or heuristic rules are used in a remote processing unit to identify optical effects which lead to error in the standard position calculation caused by said optical effects during scanning.

19. A scanning device according to claim 18, characterised in that algorithms or heuristic rules based on knowledge of the optical effects that lead to error in the standard position calculation are used in the remote processing unit to calculate an accurate position.

20. A scanning device according to claims 1 to 19, characterised in that the laser [3] may be broadband or narrowband.

21. A method of scanning an object [1] having an irregular surface including vertical or near vertical surfaces comprising relative movement between object [1] and the scanning device as a linear traverse in a direction perpendicular to the laser stripe.

22. A method of scanning according to claim 21, characterised in that the object's complete surface is scanned by a series of linear traverses of the scanning device each traverse being separated by an increment.

23. A method of scanning according to claims 21 and 22, characterised in that the increment is in the direction along the laser stripe and the magnitude of this increment is less that the viewed length of the stripe.

24. A method of scanning according to claims 21 to 23, characterised in that the magnitude of the increment can be varied by adaptive control from the remote processing unit to the machine along each traverse.

25. A scanning method according to claims 21 to 24, characterised in that the scanning traverses can be in either direction eliminating the wasted movements of rapid positioning returns between each traverse.

26. A scanning method according to claims 21 to 25, characterised in that the scanned data is analysed in real time by the processing unit to produce instructions to a machine to change the distance between the object and the scanning device.

27. A scanning method according to claims 21 to 26, characterised in that the linear traverses overlap so that a proportion of the surface is scanned at least twice.

28. A scanning method according to claims 21 to 27, characterised in that the scanning device comprises a camera [4], a laser stripe generating means [3], comprising laser optics [7], and at least one mirror [6], and that the scanning device projects at least two stripes of laser light [10] and has at least two viewing means.

29. A scanning method in that the processing unit controls a complete scan of the object or scene [3] comprising the following steps:
a) a series of traverses with minimum overlap
b) identification of areas that have been shadowed
c) adaptively controlling the machine to go back and re-scan the shadowed areas

30. A scanning method according to claims 21 to 29, characterised in that at least two exposures are made at the same or close to the same physical position, one at a different light level to the other.

Patents Act 1977
Examiner's report to the Comptroller under Section 17 (The Search Report)

Application number

GB 9226426.6

Relevant Technical fields

(i) UK Cl (Edition L) H4D (DLAX, DLAT, DLPC, DLRA)

(ii) Int Cl (Edition 5) G01B

Databases (see over)

(i) UK Patent Office

(ii) ONLINE DATABASE: WPI

Search Examiner

DR E P PLUMMER

Date of Search

5 FEBRUARY 1993

Documents considered relevant following a search in respect of claims 1

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
X,P	WO 92/08103 A1 (BOHLER) Whole document & EP 0507923 A	1 at least
X	WO 91/15732 A1 (INTELLIGENT AUTOMATION) Whole document	1 at least
X	WO 89/09378 A1 (KREON INGENIERIE) Whole document	1 at least
X	US 5067013 (KOSE OY) Whole document	1 at least
X	US 4541722 (JENKSYSTEMS) Whole document	1 at least
X	US 4529305 (WELFORD ET AL) Whole document & GB 2103355	1 at least

Category	Identity of document and relevant passages	Relevant to claim(s)

Categories of documents

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